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LIGHT FLASHES, PUPIL SIZE AND VISUAL PERFORMANCE:
AN ANALYSIS OF DISCOMFORT IN THE USE OF ELECTRO-OPTICAL AIDS

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9013D.01

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SUMMARY PAGE

THE PROBLEM

An experimental simulation of operational conditions involved in the use of electro-optical aids to night vision was performed in order to determine the causes of complaints of discomfort and fatigue by users.

FINDINGS

A highly significant correlation occurred between subjective reports of discomfort and relative amount of pupil constriction in response to brief bright lights. There was no relation however between these responses and visual performance in a visual search task.

APPLICATION

It is very likely that the cause of user's complaints is repeated exposure to sudden bright lights (amplified by the electro-optical aid much beyond their normal level), when in a semi-dark adapted state. These facts will be used in attempts to remedy causes of complaints.

ADMINISTRATIVE INFORMATION

This investigation was conducted under contract with the Navy Underwater Sound Laboratory and as part of Bureau of Medicine and Surgery Work Unit MF12.524.004-9013D. This report is No. 1 on that Work Unit. It was approved for publication on 22 January 1969 and designated as SubMedResLab Report No. 558.

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ABSTRACT

Two measures of subjects' response to brief, bright lights in their field of view have been made: (1) subjective judgments of discomfort and (2) objective measures of the amount of pupil constriction to the lights. These measures were made both before and after a long term visual search task. The results showed that those subjects who performed the search under conditions simulating the use of electro-optical aids did have greater discomfort and pupil constrictions in response to the lights. There was, however, no concomitant decrement in visual performance.

LIGHT FLASHES, PUPIL SIZE AND VISUAL PERFORMANCE: An Analysis of Discomfort in the Use of Electro-Optical Aids

INTRODUCTION

In recent years, technological advances have resulted in passive, direct view, image-intensifier systems which significantly increase the ability of men to see and to operate efficiently at night without external light sources. The systems, developed chiefly by personnel at Fort Belvoir for Army use, employ miniaturized image intensifier tubes with a total light amplification of many thousands. They can be made in a size small enough to be handheld and have proved very effective in Army night warfare.

However, the requirements for guerilla warfare differ considerably from those of Naval operations at night; the Naval Underwater Sound Laboratory, New London, Connecticut, therefore has been asked to adapt the devices for efficient Naval operations.

One of the aspects of electro-optical aids being studied by USL are the frequent complaints of discomfort or fatigue from the field by individuals using them over fairly long periods of time. The Vision Branch of the Submarine Medical Research Laboratory was given a contract (WR-8-0023) from USL to determine the basis of the complaints. Our technique for analyzing the problem was to simulate the conditions found in the field in carefully controlled laboratory measures. From the literature on discomfort and fatigue, we picked variables which appeared most relevant to the operational situation.

This literature is an extensive one and consists of two general types of information. First are the studies of subjective reports of discomfort. A technique for measuring the discomfort produced by glare sources in the field of view has been evolved and used extensively in the lighting industry. The contributions of various factors, such as the size and position of the glare source, its brightness, the viewing conditions, the subject's age, etc., have been analyzed. There is thus a method and a considerable background of data by which subjective reports of discomfort can be analyzed.[1]

Second are the numerous attempts to find physiological correlates of discomfort and fatigue. Since it is well known that there are no pain receptors in the retina, these investigations have generally focused on various oculomotor systems. Thus convergence, accommodation, pupil constriction, and blink rate have all been studied. In this area, however, the results have usually been negative; that is, there was little or no correlation between the various physiological measures and subjective complaints. For example, accommodation was at one time a prime suspect for "eye strain" and a sensitive technique, the "ergograph," was arranged to force a subject to use his accommodative mechanism extensively over long periods of time.[2] While effective in producing fatigue in elderly[3] or asthenopic subjects,[4] most young, normal subjects can continue the exercise for hours without showing any disability.[5] Similarly, subjects have been able to adjust to strenuous tasks,[6] to setting a vernier gauge for two hours,[7] and to reading for six hours[8] without sizable measures of fatigue.

One of the few positive results has been a relation between the amount of pupil constriction in response to brief flashes of light and subjective discomfort reports. Fugate and Fry[9] report that subjects call a light flash uncomfortable when their pupils constrict more than 1½ mm in response to a light. The important factor is, of course, the sudden onset of a light source whose intensity is considerably above the level to which the eye is adapted. High intensity, per se, is not necessarily uncomfortable; the pupil responds quickly and the eye adapts readily to increases in brightness. After a few seconds the bright source is no longer uncomfortable.[10]

Sudden exposures to bright lights are a common experience for operators of the electro-optical aids. The devices, designed to amplify extremely low light levels to usable quantities, also increase lights that would be visible without this amplification. The operator, scanning a night horizon, may inadvertently turn the instrument on a light source

and find his eye flooded with light 10 to 1000 times greater than the level to which he is adapted.

Since intense lights seemed to be a likely source of the complaints of discomfort in the field, the experiment was designed to provide subjects, who were adapted to a low, overall light level, with brief lights and to measure their responses to them. Two measures were made: (1) subjective judgments of whether or not flashes of various intensities were uncomfortable, and (2) objective measures of the amount of pupil constriction to the various lights. Since the electro-optical aids are monocular devices, 1/2 of the subjects were tested monocularly throughout; the other 1/2 of the subjects used binocular vision.

In order to relate subjective reports to performance, a visual search task was devised. The subject's ability to find a test target in an array of other similar targets was measured continuously for a half-hour period. The search task was performed at one of two luminance levels, 5 ft-L or 100 ft-L. The former was chosen to be representative of normal operating levels for the electro-optical aids, the latter as the brightest extreme encountered.

The experimental protocol is summarized below:

First, the subjective responses of the men to brief bright lights were recorded. Simultaneously photographs of the pupillary responses were made.

Second, the men performed a visual monitoring task, searching for a visual target for 36 min. at one of two light levels.

Third, the subjective responses and the pupil sizes were measured again. The difference between these measures and the first measures reveals the effects of the intervening search task.

APPARATUS AND PROCEDURE

Visual Performance

The subject's task in visual search was to determine whether or not a target was present in an array of similarly shaped figures. Figure 1 is an example of the task: all fig-

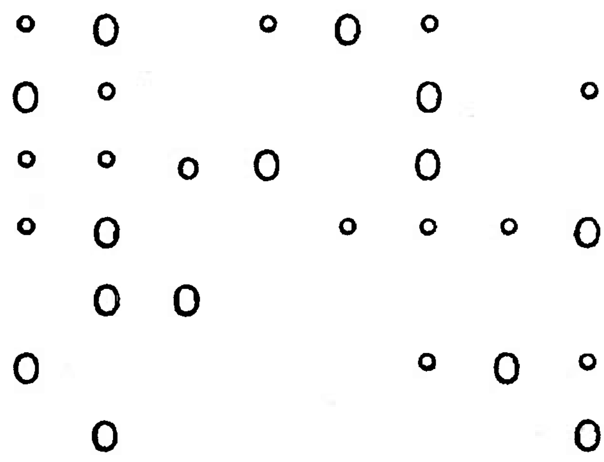

Fig. 1. An example of one of the arrays used in the visual search task. A target is present in the third row, third column.

ures were composed of 28 circles in one of two sizes, 14 large and 14 small. The target was an intermediate-sized circle; when present in an array, it replaced one of the small circles. The position of all of the circles in an array was allocated on a random basis.

The arrays were photographed and mounted as slides for projection to the subject by means of Kodak Carousel projector. A total of 240 arrays were fabricated; these were placed in six trays of 40 each. Of each of the 40 arrays, 12 contained targets, the other 28 did not. In a preliminary investigation, the difficulty of detecting the target was determined for each array. The trays were then balanced so they each contained targets of equal difficulty.

The arrays of figures were presented automatically for 4.5 seconds each. A 4.5 second interval followed each array, during which period the subject responded to the previous array. This period was the result of projecting a blank piece of cardboard on the screen, which blocked the light from the projector.

Presentation of a complete tray took six minutes; six trays were projected without interruption yielding a total monitoring time of 36 minutes. Subjects were provided with two buttons, one for "yes" and one for "no"; their responses were recorded automatically on a pen and moving paper system located in an adjacent room.

Subjective Judgments of Comfort-Discomfort

Subjects were asked to judge whether or not various intensities of light were uncomfortable when presented to them in an otherwise dark environment. The various intensities were achieved by placing neutral density filters in the Carousel projector. They were arranged in an ascending scale from .1 ft-L to 100 ft-L, in one-half log unit steps. The highest intensity, 200 ft-L, was 1/3 log unit greater than the preceding one and represented the maximum amount of light available with the Carousel projector.

Each light was presented for 4.5 seconds and was followed by 13.5 seconds of darkness. (Some diffuse illumination was present from stray light in all "dark" conditions; it measured about 5 x 10^{-4} ft-L on the screen.)

Subjects were asked to respond as to whether or not the lights were uncomfortable by pressing the same buttons for "yes" and "no" as they used in the search task.

Pupil Size Measurements

Infra-red photographs of the right pupil of each subject were taken periodically during the dark periods and during presentation of the various light intensities which the subject was simultaneously rating for comfort. A 35-mm camera, loaded with infra-red film and equipped with a close-up lens, was mounted with a view of the subject's right eye. A spot light was reflected from a mirror to the subject's eye while the camera was focused. An infra-red filter, Corning No. 2550, was then inserted in the spot light beam, enabling photographs to be taken in the darkened room.

SUBJECTS

A total of 67 enlisted men serving on submarines stationed at the Naval Submarine Base, Groton, Conn., served as subjects for the experiment. They ranged in age from 18 to 29 years, and had visual acuity of at least 20/25 without correction.

The men were assigned randomly to one of the four experimental groups: (1) monocular vision with the search task performed at 5 ft-L; (2) binocular vision at 5 ft-L; (3) monocular vision at 100 ft-L; and (4) binocular vision at 100 ft-L. Complete sets of pupil size photographs were available for only 20 of the 67 men. Of these 20, there were five in each of the four experimental groups.

THE EXPERIMENTAL MEASURES

Visual Performance

1. Results

Table I gives the average number of targets detected by each of the four experimental groups over the total 36 min. testing period. The average value of about 45 correct detections out of a possible 72 (64%) was similar for all groups irrespective of whether they viewed the display monocularly or binocularly or at a background luminance of 5 or 100 ft-L.

Table I. Mean Number of Correct Detections for Each Viewing Condition

Condition	N	Mean	σ
Monocular High Intensity	15	46.7	±8.0
Monocular Low Intensity	18	44.2	±6.8
Binocular High Intensity	18	44.7	±8.3
Binocular Low Intensity	16	48.2	±7.4

The performance of the subjects over time is plotted for the group as a whole in Fig. 2. The number of correct detections in succeeding time periods at first rose and then fell in a typical monitoring curve. Differences between time periods are however small. The differences in the performance curves for monocular vs binocular viewing and for low vs high intensities, depicted in the bottom of the figure, are likewise of minor importance.

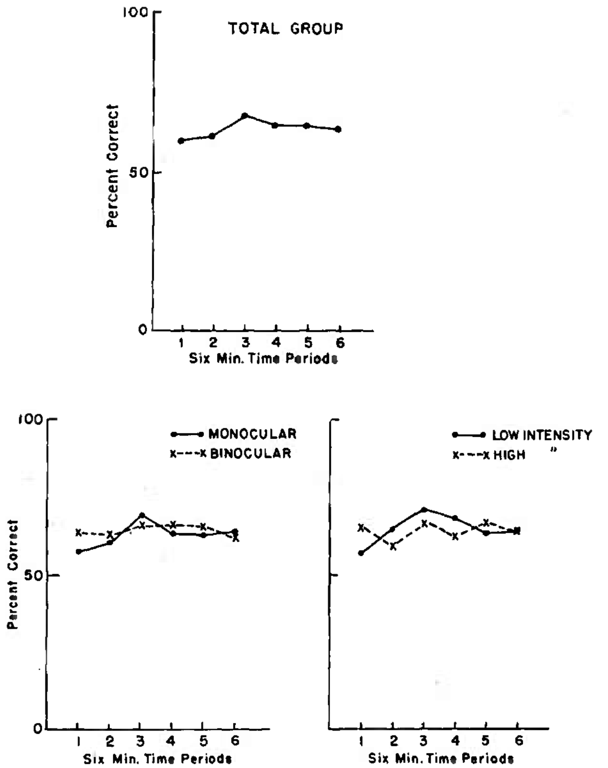

Fig. 2. The average percent correct of target identifications over the 36 minute testing period.

2. Discussion

The performance data are typical of the majority of experiments on vigilance[11] and are in agreement with general knowledge of visual functioning. There is a small practice effect or "warm-up" period in the beginning of any novel task followed by a leveling off and ultimately by a decrement as the subject becomes bored, fatigued, or generally less alert. The onset of the decrement and its severity are a function of many variables; important among these are signal rate, knowledge of results, and signal load or complexity. Small decrements are generally found with high signal rates, as used here, with knowledge of results or high signal expectancy and with relatively simple tasks.[12]

The search task itself, being supra-threshold, is not dependent upon illumination level nor on the color of the illumination. In the original standardization of the test, colored backgrounds of red, yellow, green, blue, and neutral were tried, as were illumination levels of 5 and 100 ft-L. None of these conditions resulted in differences in performance in the visual search task. The independence of performance from illumination level is repeated in the results here. At lower illumination levels, there would, of course, be a point below which the subject actually had difficulty seeing the array and amount of light, per se, would become an important factor in performance.

Similarly, the task is easy enough so that the use of both eyes does not improve performance over what can be done with one eye alone. Under conditions closer to the threshold for vision, one would expect two eyes to be better than one on a simple probability basis.[13]

3. Subjective Reports

Subjects were interviewed after the completion of the experiment regarding any difficulties they might have experienced and as to whether they found the search task easier at the beginning or end of the monitoring period. Table II presents the results of the most frequent complaint, that, after viewing for some time, all circles began to appear very similar in size. From these reports it is clear that the subjects regarded the low intensity monocular condition as the most difficult and the high intensity binocular condition as the least difficult.

Table II. Percent of Subjects Complaining About Search Task

Condition	Monocular	Binocular	Mean
Low Intensity	39%	31%	35%
High Intensity	33	17	24
Mean	36	24	

The performance data on these subjects, who complained of the increasing difficulty of the task over time was tabulated separately. Their results are compared in Fig. 3 with that of the remainder of the subjects, who stated that the task did not change in difficulty over time. The shapes of the performance curves are almost identical, indicating no correlation between subjective reports and actual performance.

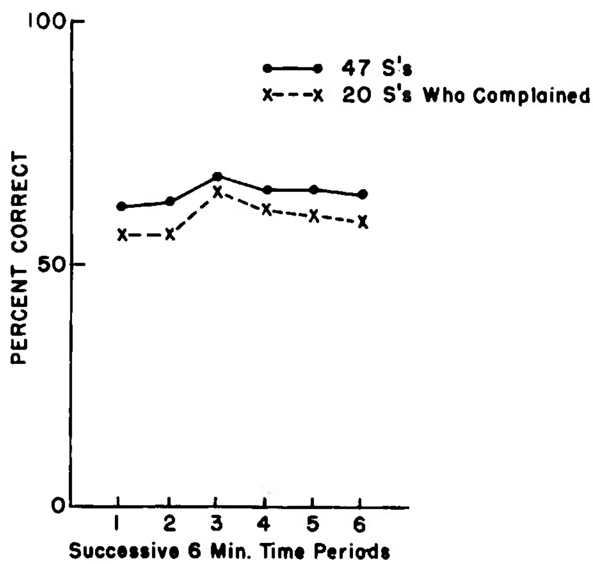

Fig. 3. A comparison of the performance over time of individuals who complained of the increasing difficulty of the search task and those who did not.

Discomfort Judgments

1. Results

The overall results of the discomfort judgments are portrayed in Fig. 4. The percentage of the 67 subjects who rated a given intensity as uncomfortable is plotted as a function of intensity. A regular, cumulative, normal distribution function was produced which increases from almost zero judgments of discomfort at .1 ft-L to nearly 100% of the men at 200 ft-L.

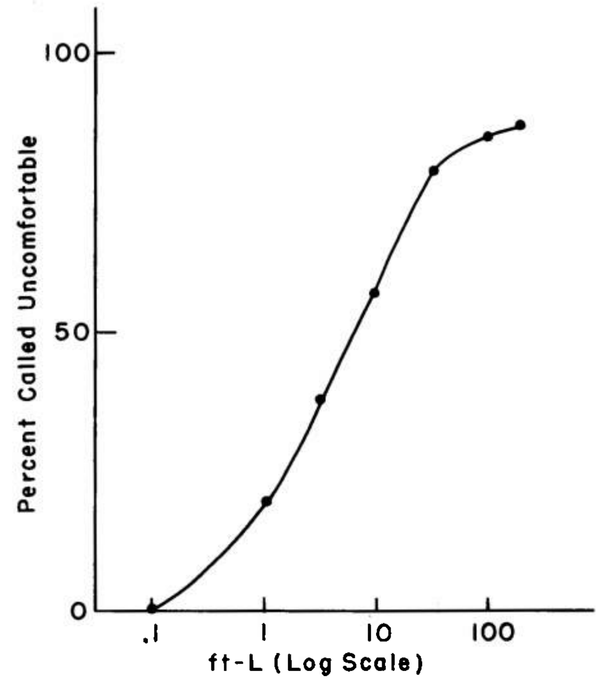

Fig. 4. The percentage of subjects reporting different luminance levels to be uncomfortable. Average of all data.

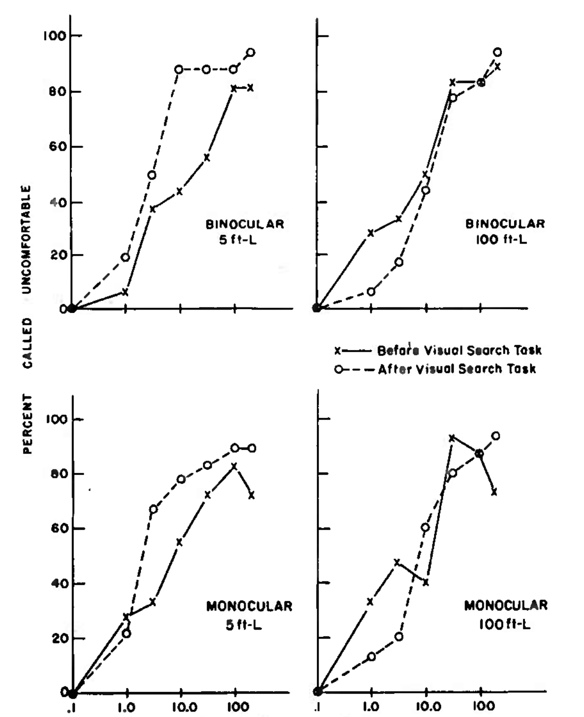

Fig. 5. The percentage of men under different experimental conditions who reported the lights as uncomfortable.

Figure 5 is a comparable analysis for the different experimental groups showing the judgments made of the various intensities before and after the monitoring task. The influence of the intervening task is apparent in the judgments. For both groups monitoring under the low intensity condition, there was a shift in the judgments; lights were rated as uncomfortable by many more men after the monitoring. Different results were found for the group who monitored under the high intensity condition. With monocular viewing there was no apparent difference between judgments before and after monitoring. With binocular viewing, the results were reversed; lights were judged as uncomfortable by more men before monitoring than after.

2. Discussion

The technique of asking the subjects to rate brief exposures of lights as to whether or not they are uncomfortable has yielded a functional relationship between the percentage of the men responding positively and the intensity of the light. The normal distribution which resulted in 50% of the men rating about 10 ft-L as uncomfortably bright is specific to these particular experimental conditions. Discomfort-glare is, of course, related to the size of the light source, the level of the background, the state of adaptation of the eye, the age of the subject, the overall sensitivity of the subject, and many other variables.

All of these variables with the exception of the state of adaptation of the eye have been held constant in the comparison of judgments before and after monitoring, thus yielding a sensitive measure of discomfort due to the specific experimental conditions. After working in a generally low light level (5 ft-L interspersed with the low background illumination), most subjects found ordinary levels of room illumination **uncom**fortable. After working in a generally high illumination level (100 ft-L interspersed with the background) more subjects judged the same lights as **com**fortable. These differences undoubtedly reflect the effect of various states of light or dark adaptation; an ordinary light can be very painful if dark adapted while very bright lights may be easily tolerated if the eyes are adapted to a generally high level of illumination. The relation between these subjective measures and changes in pupil size will be considered in the following sections.

Pupil Size

1. Results

There are considerable data available in the literature on the relationship between pupil size and light level.[14] While there are vast differences in absolute size reported by the various investigators, the functional relation between increasing illumination and decreasing pupil size is fundamental to all. A comparison between the results of the average data from this study and de Groot's summary[15] of the literature is given in Fig. 6. The average values decrease regularly in size as the light level is increased and fall within the typical range of values of previous investigations.

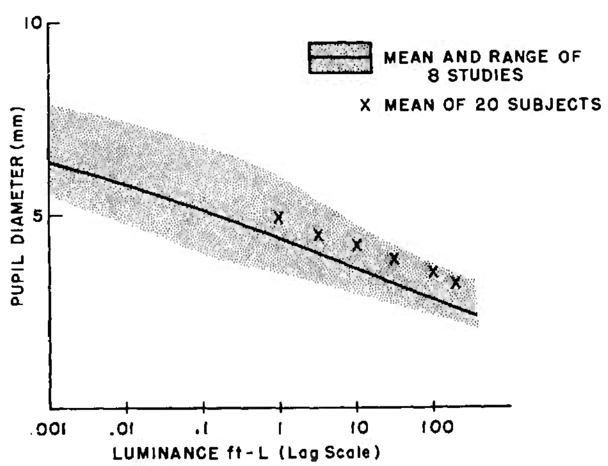

Fig. 6. Average pupil diameter for all subjects as a function of luminance level.

The reason for the differences in absolute size found in different investigations is that there are many other factors, in addition to illumination level, which affect pupil size and which may be specific to the particular experimental situation. One of these, a monocular

or binocular condition of viewing, is pertinent to this study. The pupils of the two eyes normally constrict and dilate consensually; that is, if only one eye is exposed to light, the other eye will constrict about the same amount whether or not it is exposed to light. However, the agreement between the pupil sizes of differentially illuminated eyes is never perfect; there is always some residual effect of the state of the other eye.

Figure 7 shows the absolute pupil size of the two groups of subjects who observed monocularly and binocularly in this study. The pupil sizes of the monocular group are larger throughout than those of the binocular, in agreement with the well-documented effect of patching one eye on the pupil size of the other.[16] The differences here between the monocular and binocular groups are very small but the absolute size may be obscured by the fact that different individuals form each group. Differences of .5 to 1 mm between monocular and binocular viewing in the same Ss are commonly reported.

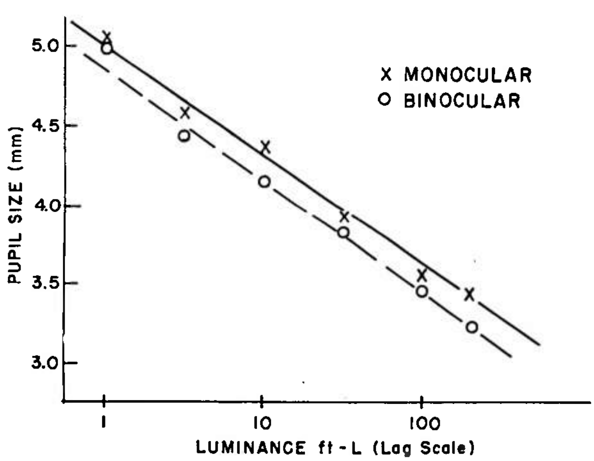

Fig. 7. A comparison of pupil sizes under monocular and binocular viewing conditions.

There are many other factors that can affect pupil size, such as the age of the subject, his state of alertness, and even his degree of interest in the task.[17] The absolute pupil size, per se, is not, however, of importance to this investigation but rather it is the relative amount of change or constriction that is related to discomfort. The rest of the pupil-size data, therefore, are reported in terms of a ratio: the size of the pupil in light to its size in the dark for each individual. Thus, a ratio of 1.0 means there was no change from light to dark while a ratio of .5 means the pupil in light is one half of its size in the immediately preceding dark period.

Figure 8 presents the pupil size data, in terms of the relative amount of constriction from dark to light, for each of the four experimental groups before and after the monitoring task. For example, before monitoring, the pupils of the subjects in the monocular low group at 1.0 ft-L were .74 of their value in the dark. After monitoring their pupils averaged .64 of their size in the dark at the same light level. This increase in the amount of constriction to light after monitoring is found throughout the entire range of intensities for this experimental group.

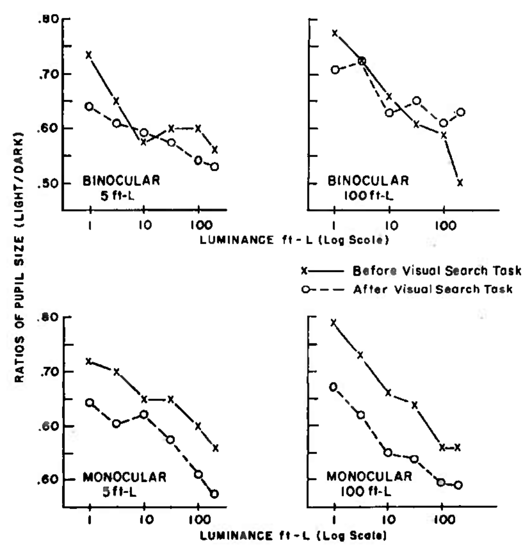

Fig. 8. The relative amount of pupil constriction to light before and after the visual search task.

Similarly the relative constriction for the group monitored monocularly under the high intensity, was much greater after the task, as was the data for the binocular, low intensity group, with the exception of one point. For the binocular high intensity group, there is no apparent difference in pupil constriction before and after monitoring.

Relation Between Pupil Size and Discomfort

1. Results

A point biserial correlation was performed between the pupil size ratios and the subjects' judgments of comfort or discomfort for each of the six illumination levels at which the pupil was photographed. The dichotomous variable was comfort or discomfort and the continuous variable, the ratio of pupil size (Light/Dark) at each light level. The results are given in Table III. The point biserial correlation of .95 is significant at greater than the .001 level.

Table III. The Relation Between Comfort-Discomfort Judgments and the Amount of Pupil Constriction

	L/D Ratio	N
Mean Pupil Size Ratio	.66	480
Mean Pupil Size Ratio No Discomfort	.64	224
Mean Pupil Size Ratio Discomfort	.56	256
$r_{pbi} = .95$		

This finding of a general relationship between amount of pupil constriction and comfort-discomfort judgments led to a further analysis. The subjective judgments of the 20 specific subjects for whom pupil sizes were available were separated from the judgments of the rest of the group. The percentage of the lights called uncomfortable by these five subjects in each of the four experimental groups is plotted in Fig. 9. The data are essentially the same as those of the larger group of subjects (Fig. 5) with the exception of a few minor details; the latter generally improve the correspondence between the comfort-discomfort judgments and amount of pupil constriction. This is particularly true for the monocular-high group. A comparison of Figs. 8 and 9 reveals good agreement between the discomfort judgments and the pupil constrictions. In general, after an extended period of visual search performed monocularly or in low illumination levels, subjects are more sensitive to bright lights and their pupils constrict more. After performing the same task binocularly at high intensities the relationship tends to reverse.

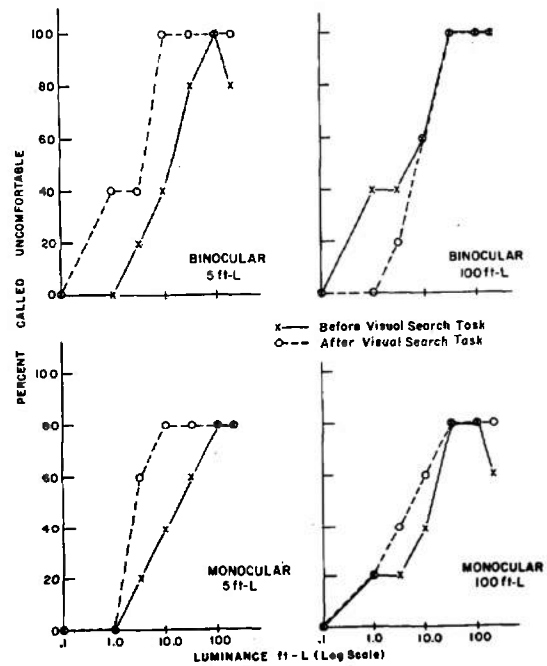

Fig. 9. The subjective judgments of comfort for the 20 specified subjects for whom complete pupil size data were available.

GENERAL DISCUSSION AND INTERPRETATION

The results of the experiment show that sudden exposures to bright lights are judged to be an uncomfortable experience by the vast majority of subjects and that they simultaneously result in correlated pupillary constrictions. The amount of constriction is dependent upon the state of adaptation of the eye and upon the viewing conditions.

The comparison of responses (both judgmental and pupillary) before and after an extended visual task is a particularly sensitive measure since individual differences are controlled. This comparison reveals that binocular viewing under a high luminance level is the only condition that does not result in greater discomfort with subsequent exposure to light. If the visual task is performed at a

low light level or if only one eye is used and the other eye is patched, subjects will be more sensitive to sudden bright lights in their fields of view.

The latter conditions are, of course, intrinsic to the use of electro-optical aids. The operator working at night is adapted to a very low light level. When he uses the device, one eye receives a moderate amount of light (1 to 10 ft-L) while the other eye remains dark adapted. The constriction of his pupil to the moderate light level is not as great as it would normally be since his other eye remains in the dark. Accidental exposure to high intensities result in sizable pupillary constrictions and in sensations of discomfort or pain.

On the other hand, there was no evidence of a decrement in performance correlated with these subjective responses. Subjects who performed the visual search task monocularly did just as well as those observing binocularly. Furthermore, the statement by subjects who complained that the search become more difficult as they continued was not supported by a performance decrement over time. Similar results were obtained in the original trials with the test using colored illumination. Of the four colors employed, red was the only illumination about which the subjects complained. While the majority of the subjects did state that they found the red to be uncomfortable, there was no corresponding decrement in performance.

This lack of correlation between complaints and performance is not at all unusual. In a large number of investigations of the effect of environmental stress on performance, subjects can and do continue to respond effectively well beyond the point at which they complain loudly about discomfort.[18] One interpretation of these data[19] is that man rarely lives up to his potential; that is, he will, if allowed, quit before he has to. However, it should be inferred from this that no performance decrement will ever be encountered, if for example, the search task is extended over time, or if other than young, healthy, males are used as subjects. Performance decrements always occur under extreme environmental stress. The only point is that subjects may be still capable long after they begin to complain.

SUMMARY

The responses of individuals to sudden exposures of bright light sources were measured both subjectively, by judgments of discomfort, and objectively, by amount of pupil constriction. These measures were made before and after an extended visual search task. Those individuals tested under conditions simulating use of the electro-optical aids (i.e., monocular viewing and low level illumination) were bothered much more by the subsequent lights; those individuals tested binocularly at high illumination levels were not. There was, however, no concomitant decrement in performance.

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13. ABSTRACT

Two measures of subjects' response to brief, bright lights in their field of view have been made: (1) subjective judgments of discomfort and (2) objective measures of the amount of pupil constriction to the lights. These measures were made both before and after a long term visual search task. The results showed that those subjects who performed the search under conditions simulating the use of electro-optical aids did have greater discomfort and pupil constrictions in response to the lights. There was, however, no concomitant decrement in visual performance.

14. KEY WORDS	LINK A		LINK B		LINK C	
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